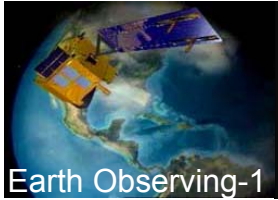


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# Section 22b

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Enhanced Formation Flying  
(JPL Algorithm)



# Abstract



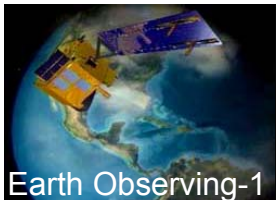
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**WHAT:** *Flight validation of autonomous navigation/formation flying technology*

**WHY:** *Formation fly EO-1 with Landsat-7 to obtain co-registered images for EO-1 camera validation*

**WHEN:** *Launch Nov. 2000, flight validation July-Sept. 2001*

**HOW:** *Use a simple algorithm that takes advantage of onboard GPS positioning to determine orbital maneuvers needed to maintain orbital formation between EO-1 and Landsat-7*

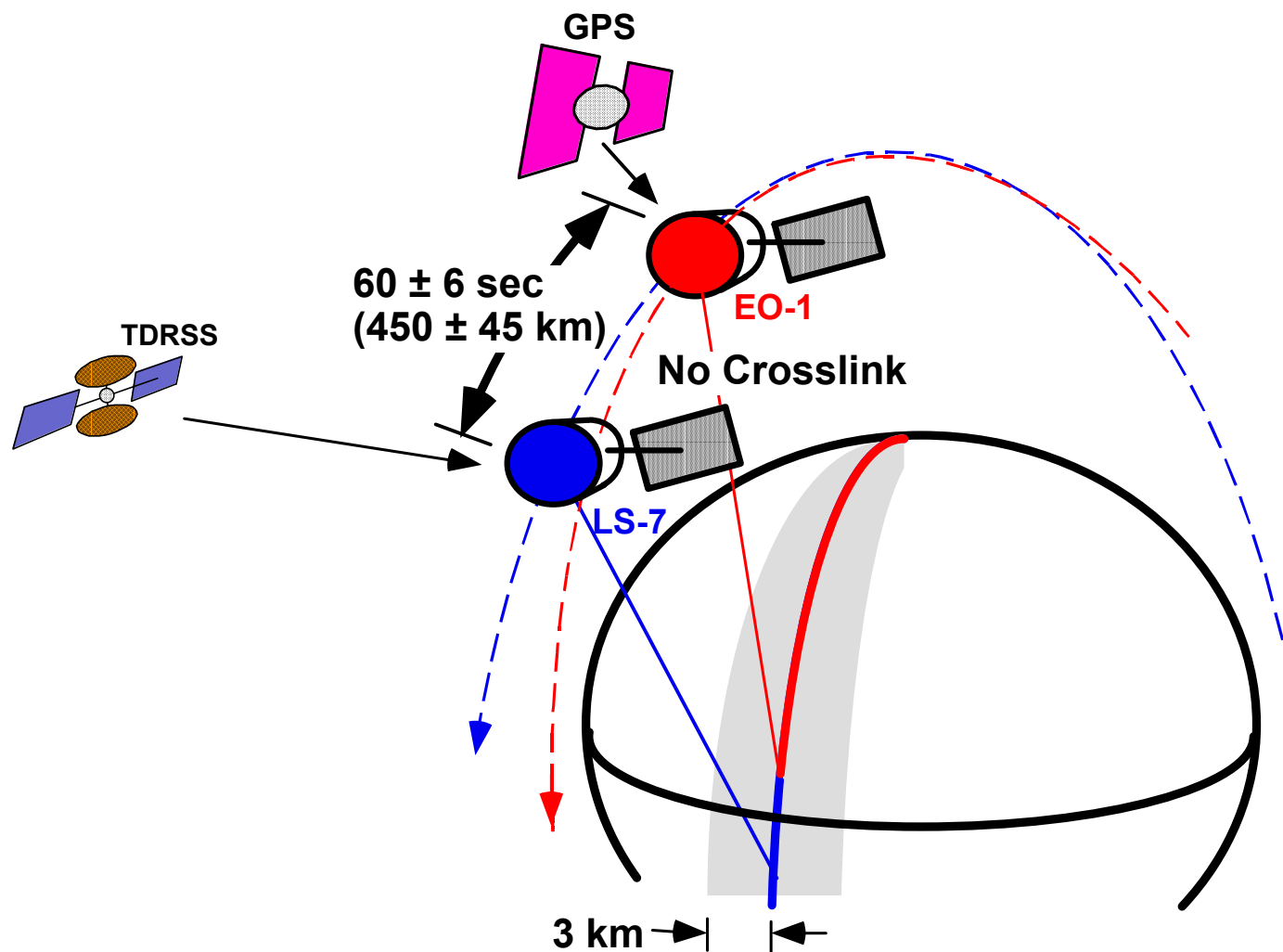


Earth Observing-1

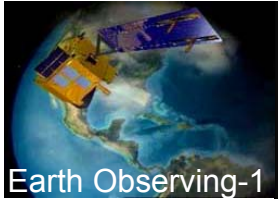
# Formation Flying Description



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**Maximum Ground Track Difference Between EO-1 and LS-7 is  $\pm 3$  km**

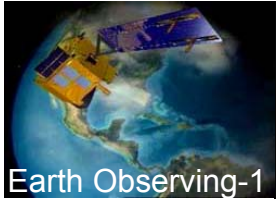


# Introduction



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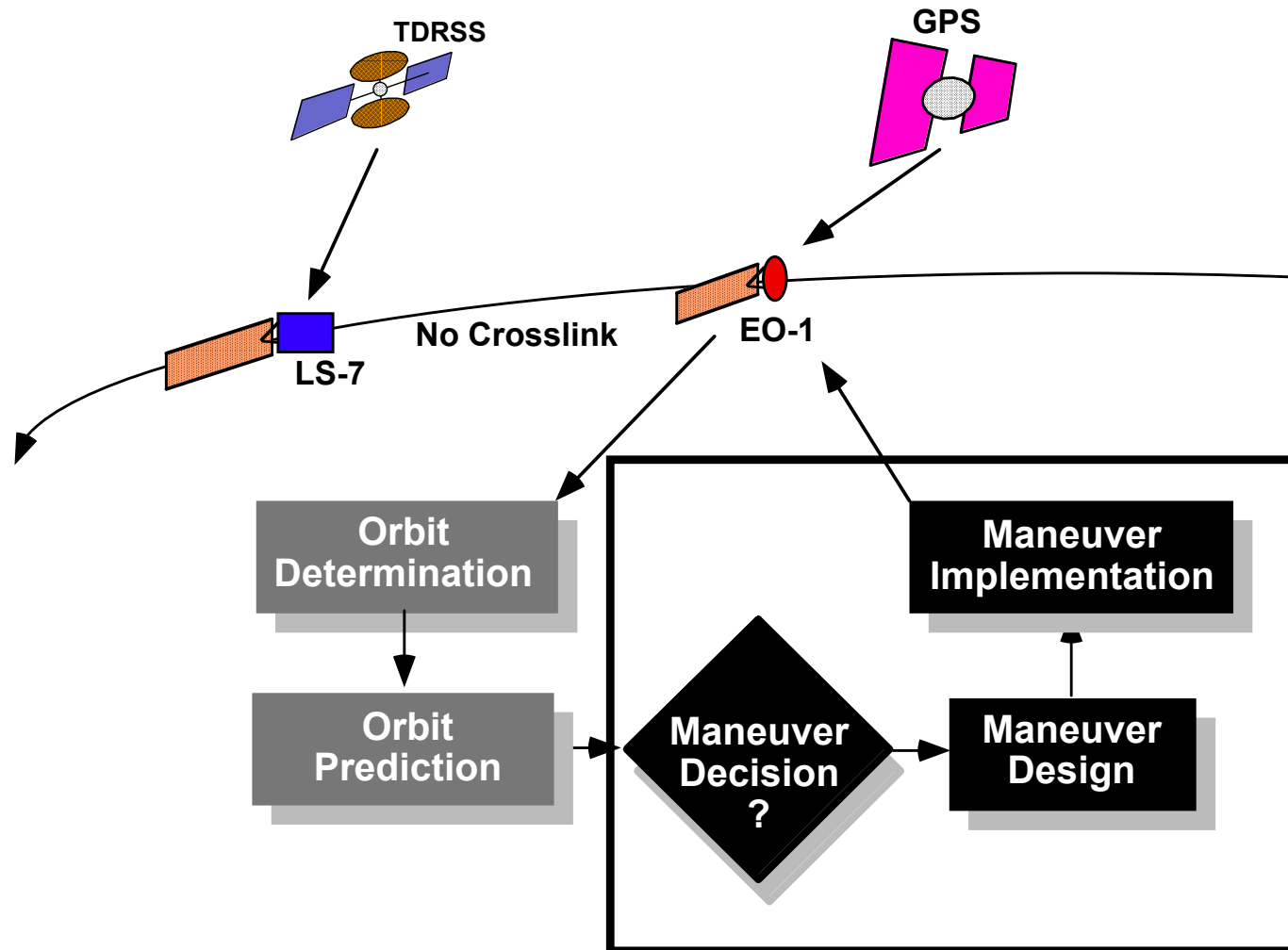
- ◆ ***Autonomous Navigation is defined as autonomously determining and controlling the orbit of a spacecraft***
- ◆ ***Autonomous formation flying is a type of autonomous navigation***
- ◆ ***Formation flying involves maintaining the translational and/or rotational states of two or more spacecraft***
- ◆ ***Benefits of JPL Autonomous Navigation Algorithm:***
  - ***Minimal memory and onboard processor requirements (<100kB RAM)***
  - ***Simple, Relies on GPS Onboard Navigation Solutions (Position Only):***
    - *No numerical integration required*
    - *No navigation (Kalman) filtering required*
  - ***Autonomous, Landsat-7 maneuvers are only routine data transmitted to EO-1***
  - ***Applicable to many future Earth science missions***
  - ***Reduced mission operations ground team effort and size***

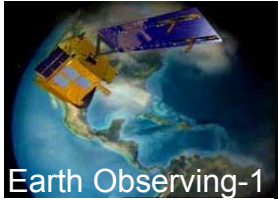


# Autonomous Navigation Elements for JPL Algorithm



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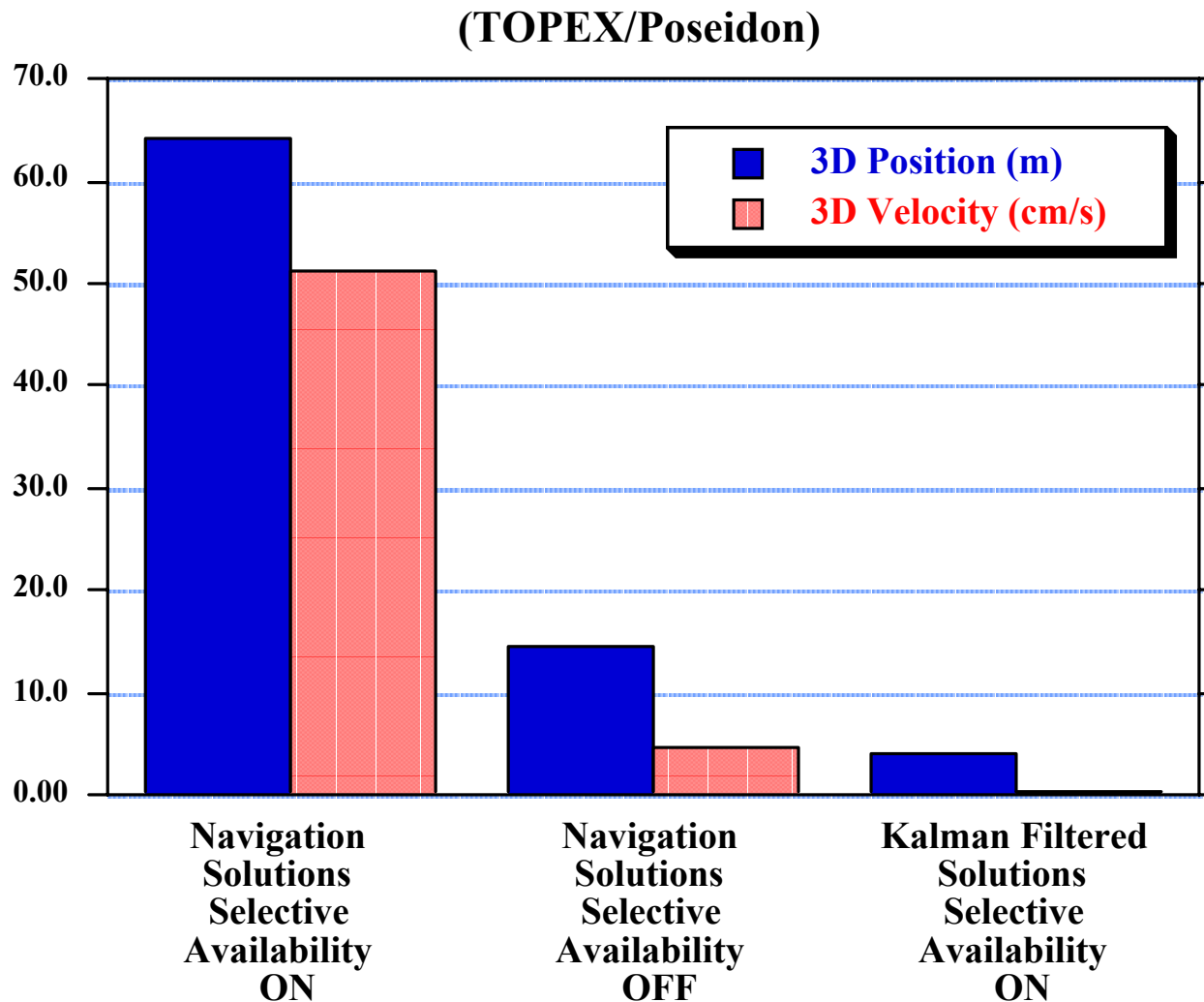


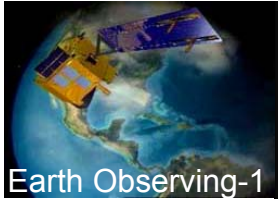


# Onboard GPS Provides Good Positioning ... but not Velocity



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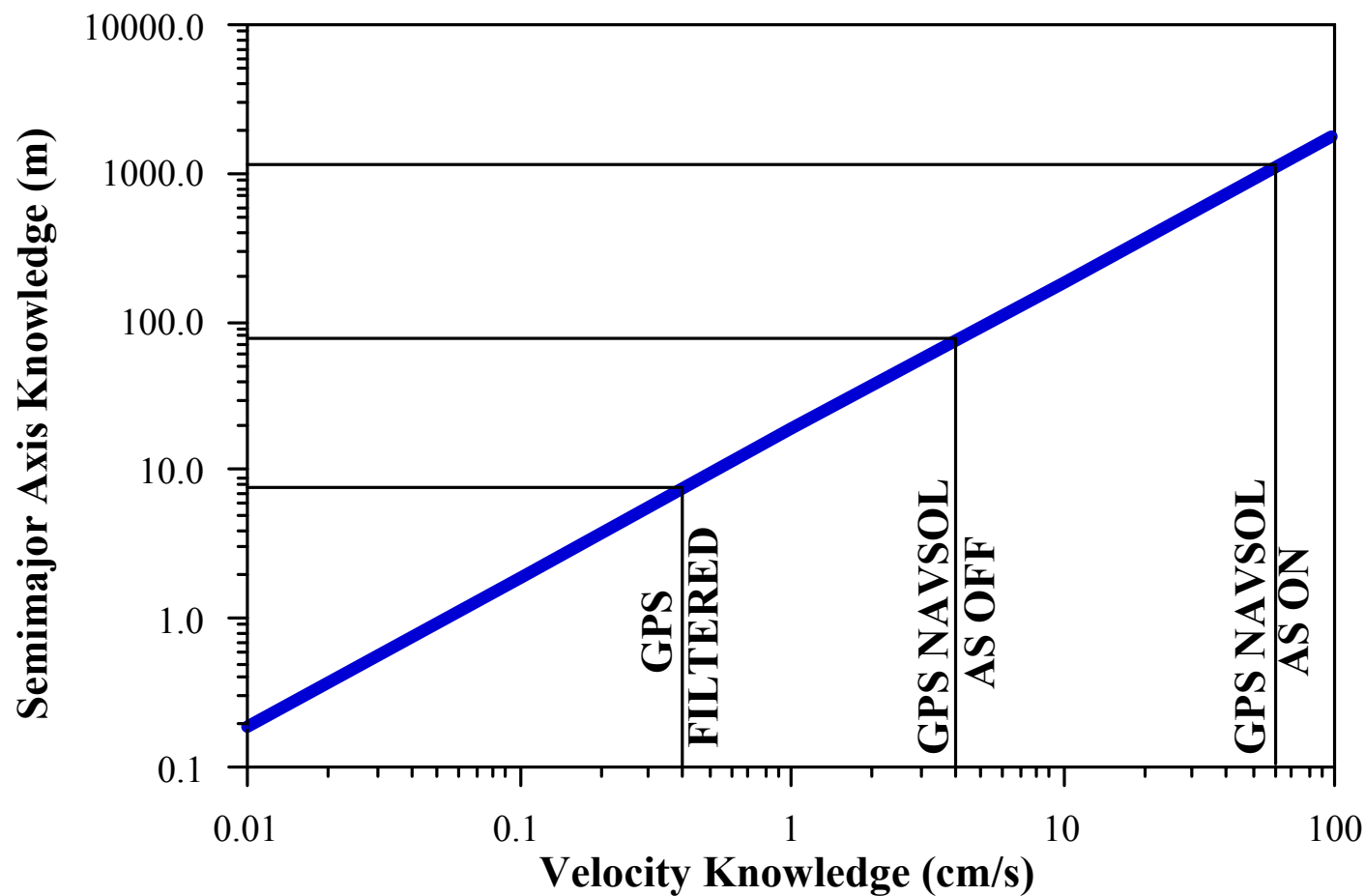
Earth Observing-1

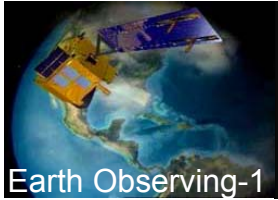
# *Semimajor Axis Requires Better Velocity Knowledge*



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## *than Onboard GPS (unfiltered) Can Provide*

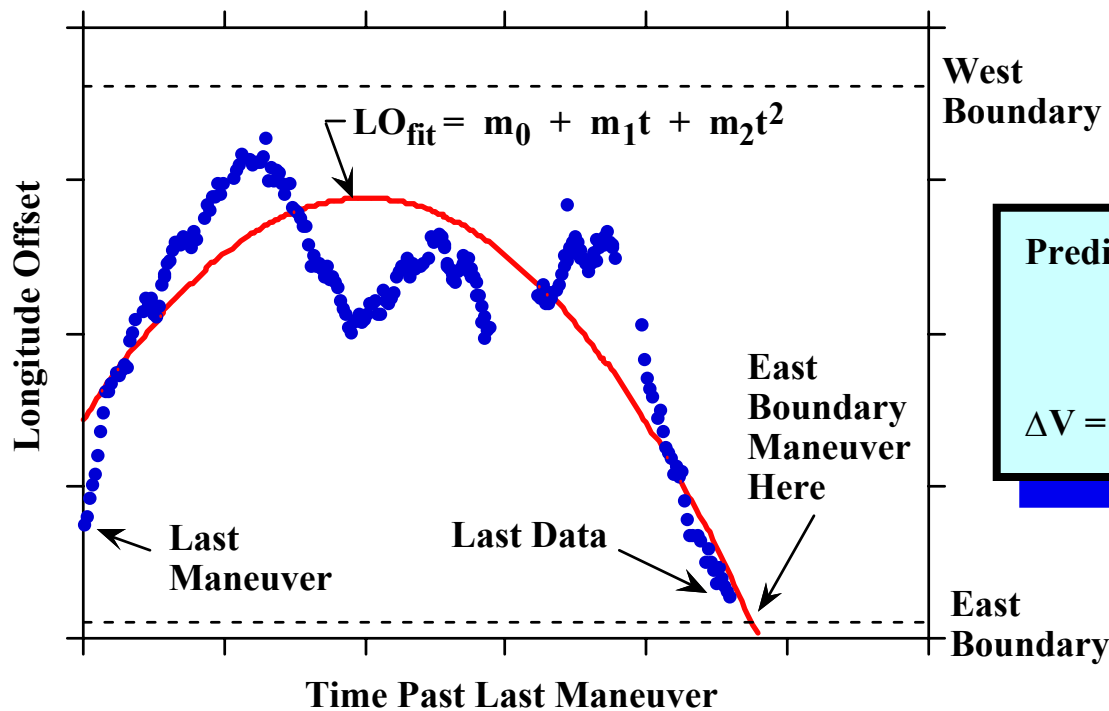




# Another Way to Get Semimajor Axis (The JPL Algorithm)



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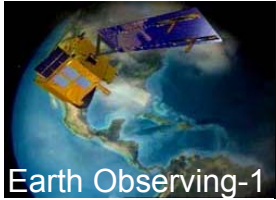


**Predicted Maneuver Time:**  
Set  $LO_{fit} = \text{East Boundary Value}$   
Solve for  $t$

$$\Delta V = f(m_0, m_1, m_2, \omega_e, a_e, V)$$

$$a = a_0 + \dot{a}(t-t_0) \quad \text{where } \dot{a} = f(m_2)$$





# *Landsat-7 Altitude Decay is Proportional to that of EO-1*



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$$\frac{\dot{a}_{\text{EO-1}}}{\dot{a}_{\text{LS-7}}} = \frac{C_D \frac{A}{m} \rho V^2}{C_D \frac{A}{m} \rho V^2} = \frac{\left(\frac{A}{m}\right)_{\text{EO-1}}}{\left(\frac{A}{m}\right)_{\text{LS-7}}}$$

where:

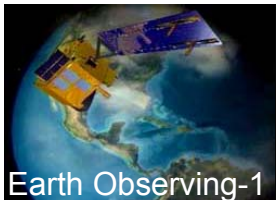
$C_D$  = Coefficient of Drag

$A$  = Area

$m$  = mass

$\rho$  = Atmospheric Density

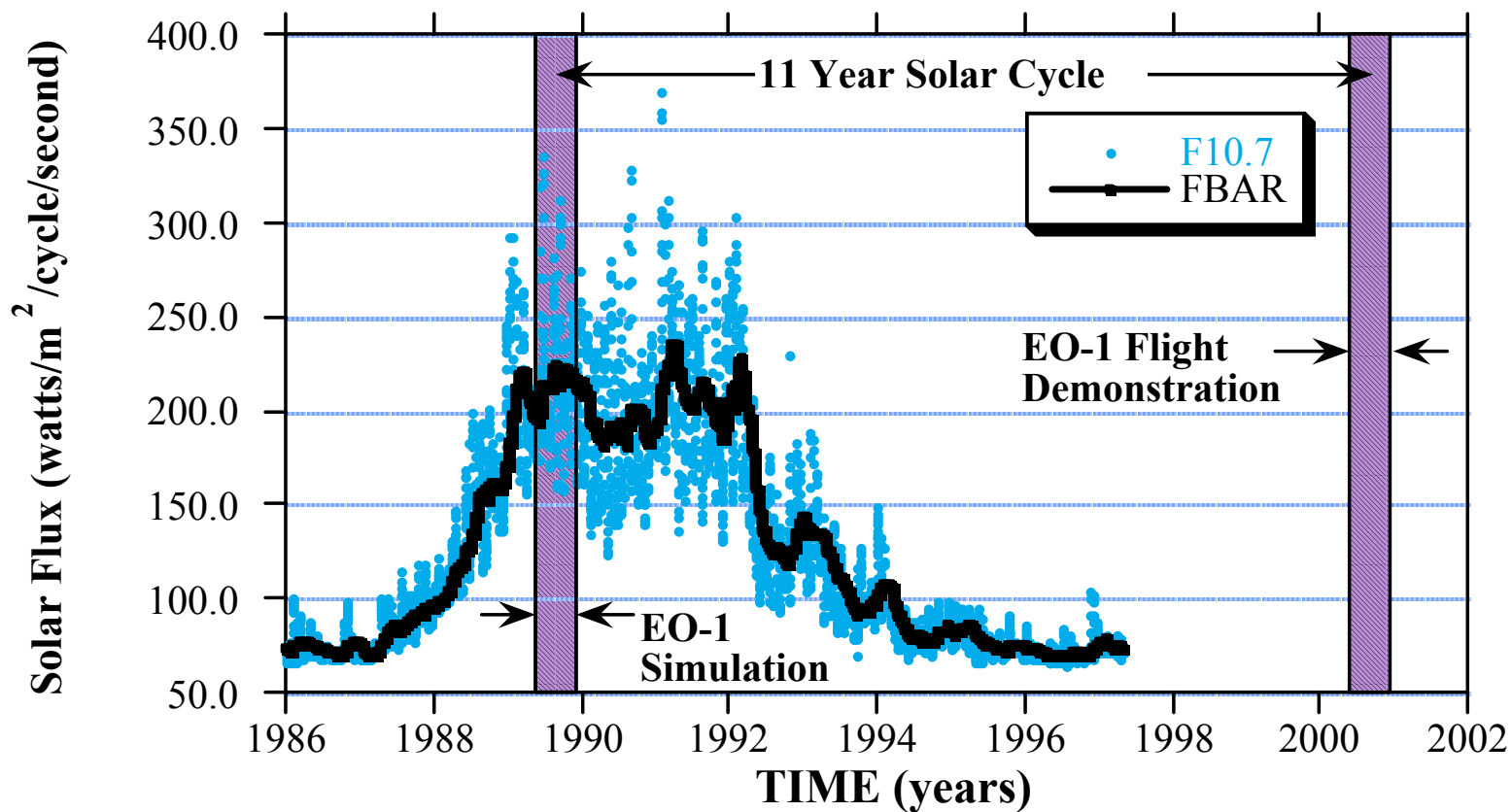
$V$  = Circular Velocity

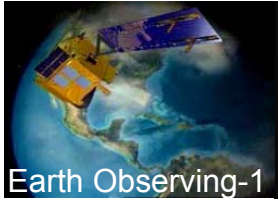


# Solar Activity Simulation



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# Conclusions



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- ◆ ***Ground validations are complete using GPS telemetry data***
- ◆ ***Flight validations will begin on July 18, 2001***
- ◆ ***Benefits of autonomous navigation***
  - ***Ground tracking network for navigation not required***
  - ***Reduces mission operations ground team effort and size***
  - ***Applicable to many future Earth science missions***
- ◆ ***Benefits of the JPL algorithm:***
  - ***Minimal memory and onboard processor requirements (<100kB RAM)***
  - ***Simple, Relies on GPS Onboard Navigation Solutions (Position Only):***
    - ***No numerical integration required***
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